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FACULTY OF COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME II

Session 6 - Environmental Systems: Management and Optimisation

Session 7 - New Methods and Technologies for Medicine and Biology

Session 8 - Embedded System Design and Application

Session 9 - Image Processing, Image Analysis and Computer Vision

Session 10 - Mobile Communications

Session 11 - Education in Computer Science and Automation

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff Rector, TU Ilmenau	Professor Christoph Ament Head of Organisation

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Rozbeh R. Alavi / Klaus Brieß

Image Processing Algorithms for Using a Moon Camera as Secondery Sensor for a Satellite Attitude Control System

Idea

Today satellites play a major roll in our life. They are not only used for communication and navigation, they also have a share in better understanding our planet and the universe. The increasing complexity of scientific questions causes higher demands to the satellites. On this reason new technical solutions are needed, which are aligned to the satellite mission.

The moon is our immediate cosmic neighbour and it still arouses interest in the astronomers. To observe the moon by a satellite from an earth orbit is a task with increasing importance. For this kind of mission objective the satellite can use a camera, which takes pictures of the moon and sends them to a ground station. One of the subsystems of a satellite is the attitude control system. It provides for stability of the satellite on its orbit. For this job several sensors are necessary to determine the actual attitude of the satellite. The most well-known sensors are: gyroscopes, magnetic field sensors, star sensors, sun sensors and earth sensors [6].

This paper examines the use of a moon camera as a secondary sensor in the attitude control loop of a satellite. The moon circle can be recognized by image processing algorithms. Then the software calculates the deviation between the centre of the moon disk and the centre of the image sensor and return two angles to the attitude control system. The emphasis of this investigation is on the application of Hough transformation for finding the parameter of the moon circle.

Difficulties

There are several difficulties to master, before the camera can be used as a sensor. The first problem is the visibility of the moon. How long the moon is visible for the satellite depends on the orbit parameters. Also before the camera can be applied as a sensor, the moon must be partially in its focus. This is one of the reasons, why the moon camera can not be used as a primary sensor. The satellite has to be brought into position with the help of other sensors before the camera is able to return reasonable values. The brightness of the moon is variable during a month. It also depends on the moon phases. For observation new moon represents a great challenge. The moon liberation also represent a difficultly for finding the parameters of the moon circle. Further difficulties are the large distance and the limited computer capacity.

Operation principles

This chapter describes the operation principles of the moon camera as a sensor of the attitude control system.

The visibility of the moon depends on the orbit parameters. The orbit parameters have to be selected for maximum visibility of the moon. Also the brightness of the moon is changing by reason of moon phases and liberation. Consequently the demands to the camera, image processing algorithms and camera computer are rising. To return useful values, the camera software needs a-priori information. For example the software can draw conclusions on the brightness and diameter of the moon disk based on current date and the actual position of the satellite on its orbit. So the necessary computer capacity drops enormous.

The attitude control system of the satellite works only if it is activated. Otherwise it is switched off to save power. In this mode the satellite rotates arbitrarily on its axes. If the attitude control system is switched on again, it is possible, that the moon is not in the field of view of the camera. In this situation the satellite has to be rotated with help of the other sensors until the camera can see a fraction of the moon. Now the camera will be integrated into the control loop (Figure 1).

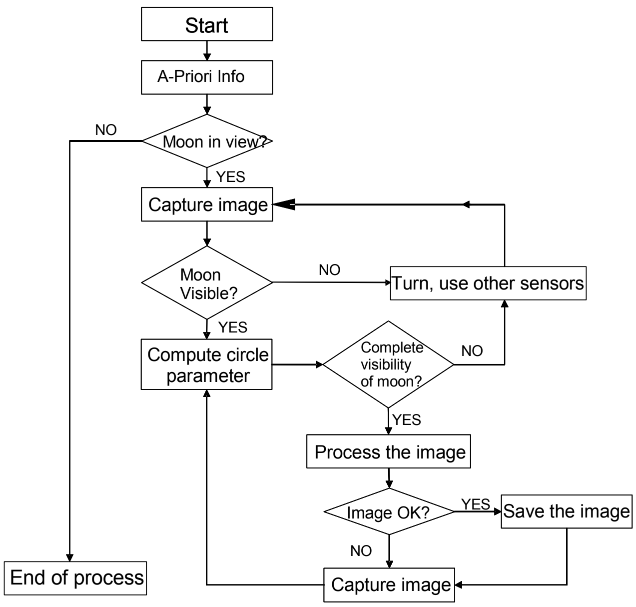

Figure 1 attitude control loop with moon camera

On a low earth orbit the distance to the moon is 400,000 km. The optics of the moon camera has to reproduce an error free picture of the moon. It is also very difficult to construct such optics space-saving.

Process model

This chapter describes the process model for the image processing of the moon camera as a secondary sensor of the attitude control system. Image processing applies in a lot of scientific fields such as medicine, astronomy, security and so on. It also can be used in a moon camera as image sensor.

An image is an information source. The information of an image is distributed in several layers. For using this information some mathematical algorithms have to be applied. For our application there are four types, which help to find the parameters - diameter and centre of the disk - of the moon circle. The figure 2 shows the stepwise processing of a moon image.

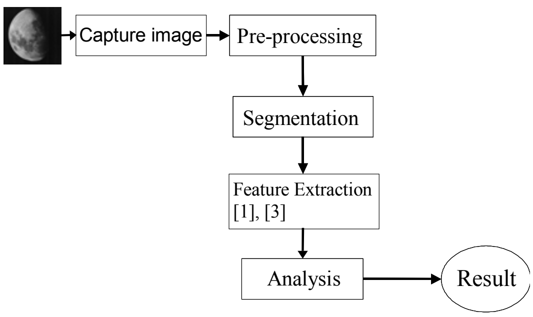

Figure 2 process model

Pre-processing

The first step after capturing a picture is the pre-processing. In this phase of operation the information content of the image has to be reduced. This step is very important, because of the limited storage and processing resources of a satellite. Also the quality of the image can be improved by special filtering operations.

Segmentation

Segmentation is the next step. In this phase interesting segments of an image have to be extracted. So it is possible to cluster the objects of an image. For solving this problem several filter operations also morphological operations are needed [1]. At this point the information content of the picture is reduced to the most important objects on it.

Feature Extraction

After finding and clustering the objects of interest, their characteristics have to be determined. This phase of the process model is often very complex and needs more computer capacity. Hough transformation is used in our application to extract features.

Analysis

In the last phase of the process model the computed feature parameters have to be analysed. In our application the actual attitude of the satellite can be computed based on the parameters of the moon circle.

Implementation of the process model

This chapter describes the implementation of the process model. The intention here is to find the moon disk in a taken picture and calculate its parameter such as diameter and its centre. The actual attitude of the satellite can now be computed based on the deviation between the centre of the moon disk and the centre of the image sensor. The figure 3 shows the process model for the moon camera.

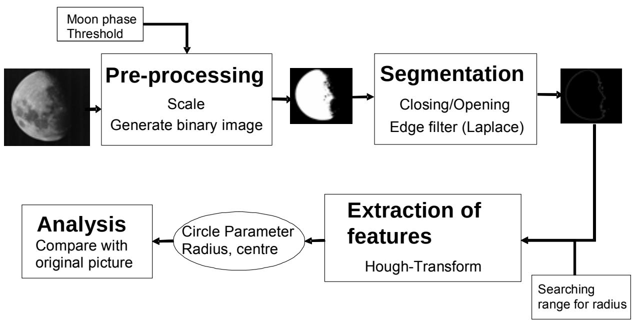

Figure 3 process model applied on the moon image

After capturing a picture the system begins the pre-processing. At first the picture can be scaled. This allows lossless reduction of relevant information, because the moon is a relatively homogenous structure. In this phase the system needs a-priori information, such as moon phase to define a threshold for generating a binary picture. The output of this operation step is a small binary picture of the moon.

In the next phase the moon disk has to be extracted. Dependent on the moon phase and on its brightness, there might be structures visible, which complicate the calculation of the disc parameters. This problem can be mastered by morphological operators, such as closing or opening. The result of this step is a homogenous moon area. The edge of this area can be detected by edge operators. Because the attitude of the camera is unknown, it is helpful to use an operator with second derivative, such as Laplace [2], [3]. Also the relative position especially the rotation between the moon and the sensor becomes neglectable.

$$\Delta^2 f(x,y) = \begin{pmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

Equation 1 Laplace matrix

After the segmentation phase the information of the moon image is reduced to a circle or a circle fraction.

In the next step the Hough Transform will be used to find the circle parameters. P.V.C. Hough developed this Transform to detect straight lines in 1962 [4], [5]. During this transformation a discrete parameter space will be defined, named accumulator. Each point in the original image builds a curve in the parameter space. A representation of a straight line is given by:

$$\vec{n} * (\vec{x} - \vec{a}) = \begin{pmatrix} \cos\theta \\ \sin\theta \end{pmatrix} * \left(\begin{pmatrix} x \\ y \end{pmatrix} - \rho \begin{pmatrix} \cos\theta \\ \sin\theta \end{pmatrix} \right) = x\cos\theta + y\sin\theta - \rho = 0$$

$$\Rightarrow$$

$$\rho = x\cos\theta + y\sin\theta$$

Equation 2 Parametric equation for a straight line

Where ρ is the distance of the line from the origin and θ is the angle between this perpendicular and the x-axis. Our parameter space is now in ρ and θ. θ can take values between 0 and 2π and ρ is limited by the image size. For each point with (x, y) coordinates and for each angle the distance ρ will be calculated. The peak in the accumulator array defines the equation of the line. The figure 4 shows an example.

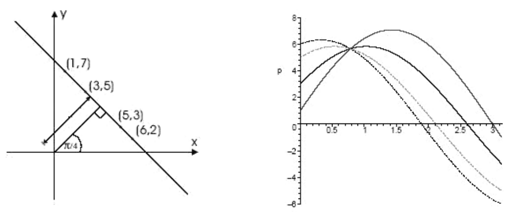

Figure 4 Example for Hough Transform

The Hough Transform works for other geometrical figures too. A representation of a circle is given by:

$$r^2 = (x-a)^2 + (y-b)^2$$

Equation 3 Parametric equation of a circle

Where r is the radius of the circle and a and b are the relative distance of the centre of the circle from the origin. As is evident from the equation the parameter space has three dimensions. This is the reason, why the computing time can be enormous. Well chosen pre-processing algorithms and segmentation drop the computing capacity and computing time.

At last the finding parameters can be compared with the original image to control the results. If the calculated values are acceptable, the angular deviation of the satellite can be defined by these values and the optic parameters.

Discussion

In this chapter the results of this application will be discussed. For testing the functionality of this method software was written. It grabs a picture from a CCD camera and applies the described process model on it. Technical specifications of the camera: Plunix TM-6EX, Sensor: 1/2” CCD, Resolution: 560(H) X 420(V), Pixel: 8.6µm X 8.3µm.

The accuracy of the process model was tested by using a picture of a circle. The table below represents the optic parameters. The accuracy depends on the camera resolution and size of the sensor pixels. Also the camera optics plays a major roll. With our test stand we could measure a deviation of 0.2°

Parameters				
Pixel (HxV)	8.6	µm	8.3	µm
Pixel average	8.4	µm		
Focal distance f	12	mm		
f-number	2.8			
Image distance	12.3	mm		
Object distance	458	mm		
Reproduction scale	0.03			

Table 1Optic parameters

The process model was applied on a moon image too. The picture represents a nine days old moon. The image distance was 633mm. After grabbing the picture it was scaled with a factor of 1/6. After scaling a binary image was generated. For eliminating troublesome structure morphological operators - closing and opening - were applied on the picture. With help of Laplace operator the moon disc was reduced to its edge. After that the Hough Transform calculated the circle parameters. The figure 6 shows the operation steps.

Figure 5 Result of image processing steps

The cycle takes ca. 0.7s on an ordinary PC with 2.4GHz Intel Processor. The radius of the moon was detected with an accuracy of 3 pixels.

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